Rec'd PCT/PTO 29 MAR 2001

FORM PTO-1390 (Modified) (REV 11-98) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER	**205275US2PCT**
U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR	09/787905

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/JP99/05110	**20 SEPTEMBER 1999**	**30 SEPTEMBER 1998**

TITLE OF INVENTION
METHOD OF ANALYZING CORROSION AND CORROSION PREVENTION

APPLICANT(S) FOR DO/EO/US
Matsuho MIYASAKA, et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☒ has been transmitted by the International Bureau.
   - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☐ have been transmitted by the International Bureau.
   - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   - d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 20 below concern document(s) or information included:

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☐ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ Certificate of Mailing by Express Mail
20. ☒ Other items or information:

Request for Consideration of Documents Cited in International Search Report
Notice of Priority
PCT/IB/304
PCT/IB/308
Amended Sheets (Pages 16 and 17)
Drawings (6 sheets)

JC03 Rec'd PCT/PTO 29 MAR 2001

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09/787905	PCT/JP99/05110	205275US2PCT

21. The following fees are submitted:.	CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :		
☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1,000.00**		
☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but Internation Search Report prepared by the EPO or JPO **$860.00**		
☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO **$710.00**		
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$690.00**		
☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	**$860.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).	**$0.00**	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	4 - 20 =	0	x $18.00	**$0.00**	
Independent claims	1 - 3 =	0	x $80.00	**$0.00**	
Multiple Dependent Claims **(check if applicable)**.			☐	**$0.00**	
	TOTAL OF ABOVE CALCULATIONS =			**$860.00**	
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) **(check if applicable).** ☐				**$0.00**	
	SUBTOTAL =			**$860.00**	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +				**$0.00**	
	TOTAL NATIONAL FEE =			**$860.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).** ☐				**$0.00**	
	TOTAL FEES ENCLOSED =			**$860.00**	
				Amount to be: refunded	$
				charged	$

☒ A check in the amount of **$860.00** to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. in the amount of to cover the above fees. A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **15-0030** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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24,618
REGISTRATION NUMBER

March 29 2001
DATE

6/PRTS

09/787905

JC03 Rec'd PCT/PTO 29 MAR 2001

DESCRIPTION

METHOD OF ANALYZING CORROSION AND CORROSION PREVENTION

Technical Field

The present invention relates to an analyzing method, which uses a computer for predicting corrosion and corrosion prevention. More particularly, the present invention provides an analyzing method that is preferably applicable to the problem of macro-cell corrosion (cathodic protection) such as heterogeneity metal contacting corrosion such as galvanic corrosion and differential aeration corrosion among the problems of metal corrosion and corrosion prevention. The present invention is also applicable to a system in plating, battery cell, and electrolytic tank, where an anode and a cathode are macroscopically disposed with an electrolyte interposed therebetween to form a potential field, other than the problems of metal corrosion and corrosion prevention.

Background Art

In a solution having a high electric conductivity such as seawater, an object tends to suffer damage due to macrocell corrosion such as galvanic corrosion caused when different metal materials are used or flow velocity corrosion caused by an irregular flow velocity distribution (differential aeration corrosion caused by a flow velocity difference). It has been desired to accurately predict those types of corrosion in advance and provide

countermeasures against them. "Cathodic protection" based on the positive utilization of a corrosion inhibiting phenomenon on the cathode of a macrocell is widely used as a most basic corrosion prevention process. It is required for cathodic protection to predict a corrosion prevention range and the rate of consumption of a sacrificial anode depending on the material and location of the anode, the shape, material, and arrangement of a device to be protected against corrosion, and solution conditions (electric conductivity and flow velocity).

There are limitations on an experimental approach to the prediction of a macrocell because the shape of the field has a large effect on the behavior of the macrocell. Specifically, for example, even if an experiment is conducted on galvanic corrosion and the effects of various factors including an area ratio, a combination of materials, and the electric conductivity of a solution are studied in detail, the results are only applicable to the three-dimensional shape of a region that is occupied by the solution in the experiment. Since actual devices and structures are of complex shapes, it is not possible to accurately estimate a liquid junction resistance in a macrocell, and it is difficult to apply experimental results directly. Furthermore, each time the shape of a device to be protected against corrosion is changed, it is practically impossible to conduct an experiment by assuming the changed shape.

Therefore, it has been customary to predict

macrocell corrosion and cathodic protection on a real structure according to empirical rules in most cases. Many attempts have been made to perform more accurate, quantitative predictions. According to one effort, potential and current density distributions are determined by purely mathematically solving a Laplace equation, which governs a potential distribution. However, objects to be analyzed are limited to relatively simple systems such as flat plates, cylinders, etc. While a conformal mapping process and a process using an electrically conductive paper have been employed for a long time as a process for analyzing an electric field problem, these processes can handle only a two-dimensional field.

With the development of the computer technology in recent years, attempts have widely been made to apply a numerical analysis based on a differential method, a finite element method, and a boundary element method. However, the differential method and the finite element method are disadvantageous in that they require a long computational time as the overall object has to be divided into elements. According to the boundary element method, on the other hand, the time required for dividing the object into elements and performing computations can greatly be shortened because only the surface of the object needs to be divided into elements. Considering that the boundary element method is an optimum process for analyzing a corrosion problem where physical quantities on the surface such as a potential and a current density are important, the inventor of the present

invention has developed an analyzing technique, which has applied the boundary element method to the prediction of macrocell corrosion and cathodic protection problems.

[Fundamental equations and boundary conditions]

The corrosion of a metal in an aqueous solution progresses as an electrochemical reaction in the form of an anodic reaction and a cathodic reaction, which are paired with each other. For example, with respect to the corrosion of iron in a neutral aqueous solution of salt containing dissolved oxygen, such as seawater, the reactions progress as indicated by the equations (1) and (2):

$$Fe \rightarrow Fe_2 + 2e^- \text{ (anodic reaction)} \qquad (1)$$

$$1/2 \cdot O_2 + H_2O + 2e^- \rightarrow 2OH^- \text{ (cathodic reaction)} \qquad (2)$$

On a surface of metal, a region where an anodic reaction is taking place is referred to as an anode, and a region where a cathodic reaction is taking place is referred to as a cathode. Usually an anode and a cathode are minute and mixed with each other, and their positions are not constant. Therefore, corrosion progresses substantially uniformly as a whole while being subjected to some irregularities. However, if the material, the surface state, and the environment are not uniform, then the anode and the cathode are localized, and corrosion is concentrated on a certain location (anode region). The former is referred to as microcell corrosion (cell refers to a battery cell), and the latter is referred to as macrocell corrosion. Seawater pumps are often significantly damaged primarily by macrocell corrosion such as galvanic corrosion or

differential aeration corrosion. The cathode in macrocell corrosion is inhibited from corrosion as only a cathode current flows through the cathode. A method of corrosion prevention which positively utilizes this corrosion inhibiting phenomenon is cathodic protection.

Either of systems of macrocell corrosion and cathodic protection can be considered as a cell in which an anode and a cathode are present with an electrolyte interposed therebetween. A potential (ϕ) in the electrolyte is governed by the following Laplace equation (3):

$$\nabla^2\Phi = 0 \qquad (3)$$

It is assumed that, as shown in FIG. 1 of the accompanying drawings, the electrolyte is surrounded by boundaries Γ_1, Γ_2, Γ_{3a}, and Γ_{3c} where Γ_1 represents a boundary (a boundary with a constant potential) where the value of potential ϕ is fixed to ϕ_0, Γ_2 represents a boundary (a boundary with a constant current density) where the value of current density q is fixed to q_0, and Γ_{3a} and Γ_{3c} represent the surfaces of the anode and the cathode, respectively.

Boundary conditions at the respective boundaries are given by the following equations:

$$\text{On } \Gamma_1\text{: } \Phi = \Phi_0 \qquad (4)$$

$$\text{On } \Gamma_2\text{: } q \; \{\equiv K\partial\Phi/\partial n\} = q_0 \qquad (5)$$

$$\text{On } \Gamma_{3a}\text{: } \Phi = - f_a(q) \qquad (6)$$

$$\text{On } \Gamma_{3c}\text{: } \Phi = - f_c(q) \qquad (7)$$

where κ represents the electric conductivity of the electrolyte, $\partial/\partial n$ represents a differential in the direction of an outward normal, and $f_a(q)$ and $f_c(q)$ represent

nonlinear functions indicative of polarization characteristics of the anode and the cathode, which can be determined experimentally. When the equation (3) is solved with respect to the equations (4) through (7) representing boundary conditions, potential and current density distributions in the vicinity of the surface can be determined. The potential ϕ and an electrode potential E that is to be actually measured are related to each other by $\phi = - E$.

[Solution according to the boundary element method]

Upon ordinary formulation of the boundary element method, a boundary integral equation is derived according to the equation (3):

$$ck\phi = \int_\Gamma \phi^* q d\Gamma - \int_\Gamma \phi q^* d\Gamma \qquad (8)$$

where ϕ^* represents the fundamental solution of a three-dimensional Laplace equation, $q^* = \kappa\partial\phi^*/\partial n$, Γ represents boundaries ($= \Gamma_1 + \Gamma_2 + \Gamma_{3a} + \Gamma_{3c}$) surrounding the electrolyte, and c is $c = 1/2$ for smooth boundaries and $c = \omega/2\pi$ at an angular point of angle ω.

In order to numerically solve the boundary integral equation, it is necessary to make it discrete. When the boundaries are divided into many elements and ϕ, q are approximated by discrete values at respective nodal points and interpolating functions, the following simultaneous system of algebraic equations is derived:

$$[A]\begin{Bmatrix} xj \\ qj \end{Bmatrix} = [B]\begin{Bmatrix} bj \\ f_j(q_j) \end{Bmatrix} \quad (9)$$

where b_j ($j = 1, 2, \cdots, p$) represents the value of a known component of ϕ or q on the boundaries $\Gamma_1 + \Gamma_2$, x_j ($j = 1, 2, \cdots, p$) represents an unknown quantity corresponding to b_j, $f_j(q_j)$ ($j = 1, 2, \cdots, s$) represents a nonlinear function indicative of polarization characteristics, p and s represent the numbers of elements on the boundaries $\Gamma_1 + \Gamma_2$ and $\Gamma_{3a} + \Gamma_{3c}$, and [A] and [B] represent matrixes determined by the geometrical shape of the boundary Γ. Since this equation is nonlinear, repeated calculations are required to solve the equation. The inventor employs the Newton-Raphson method.

[Process of analyzing axially symmetric region]

Many actual devices such as some pipe or pump components include axially symmetric regions, and it is desired to analyze these axially symmetric regions more simply. The following two methods are chiefly considered as a process of solving an axially symmetric problem. Namely, (i) a method of using a fundamental solution for an axially symmetric problem, and (ii) a method of using an ordinary fundamental solution for a three-dimensional problem and reducing the number of elements in view of axial symmetry when making boundaries discrete. Using a fundamental solution which meets an axially symmetric condition poses a problem in that integral calculations become more complex than using an ordinary fundamental solution. The present program employs a method of reducing the number of elements

in view of axial symmetry when making boundaries discrete. This method will be described below.

In an ordinary three-dimensional analysis, it is necessary to divide all boundaries into elements in order to make the boundary integral equation (8) discrete. However, since ϕ and q have the same value in the circumferential direction due to axial symmetry, the equation (8) can be modified as follows:

$$kc\phi = \int_{\Gamma_{ID}} \left(q \int_0^{2\pi} r\phi^* d\theta - \phi \int_0^{2\pi} rq^* d\theta \right) d\Gamma \tag{10}$$

where Γ_{ID} represents a range on a one-dimensional line. From the equation (10), a simultaneous system of algebraic equations can be obtained simply by making Γ_{ID} discrete. Therefore, based on axial symmetry, the number of unknowns can greatly be reduced, and the accuracy can be increased.

[Region dividing method]

For the sake of brevity, a region made up of two parts is considered as shown in FIG. 2 of the accompanying drawings. If an internal boundary plane is represented by Γ_B, then since the equation (9) is satisfied in each of the regions, the following equation is satisfied:

Region I

$$[A^I G^{IB}] \begin{Bmatrix} X^I \\ q^{IB} \end{Bmatrix} = [B^I H^{IB}] \begin{Bmatrix} b^I \\ \phi^{IB} \end{Bmatrix} \tag{11}$$

Region II

$$[A^{II} G^{IIB}]\begin{Bmatrix} X^{II} \\ q^{IIB} \end{Bmatrix} = [B^{II} H^{IIB}]\begin{Bmatrix} b^{II} \\ \phi^{IIB} \end{Bmatrix}$$

(12)

where the suffixes I, II represent quantities relative to the respective regions I, II, and the suffix B represents a quantity relative to the internal boundary plane Γ_B. $\{X^M\}$ (M = I, II) represents a vector having as its elements quantities relative to boundaries other than the internal boundary plane Γ_B among x_i and q_i, $\{b^M\}$ (M = I, II) represents a vector having as its elements known quantities corresponding to X^M (or a function representing a polarization curve).

Since a potential and a current density are continuous in the internal boundary, the following equations are satisfied:

$$\phi^{IB} = \phi^{IIB} \qquad (13)$$

$$q^{IB} = -\, q^{IIB} \qquad (14)$$

In the equations (11) and (12), if $[H^{MB}]\{\phi^{MB}\}$ (M = I, II) on the right side is transferred to the left side, and the equations (13) and (14) are substituted, then the following equations are obtained:

$$[A^I G^{IB} - H^{IB}]\begin{Bmatrix} X^I \\ q^{IB} \\ \phi^{IB} \end{Bmatrix} = [B^I]\{b^I\}$$

(15)

$$[-G^{IIB} - H^{IIB} A^{II}]\begin{Bmatrix} q^{IB} \\ \phi^{IB} \\ X^{II} \end{Bmatrix} = [B^{II}]\{b^{II}\} \qquad (16)$$

These equations can be combined into the following equation:

$$\begin{bmatrix} A^{I}G^{IB} - H^{IB}0 \\ 0 - G^{IIB} - H^{IIB}A^{II} \end{bmatrix} \begin{Bmatrix} X^{I} \\ q^{IB} \\ \phi^{IB} \\ X^{II} \end{Bmatrix} = \begin{bmatrix} B^{I}0 \\ 0B^{II} \end{bmatrix} \begin{Bmatrix} b^{I} \\ b^{II} \end{Bmatrix} \tag{17}$$

This equation is a nonlinear equation as with the equation (9).

As described above, the inventor has developed six programs for analyzing an open region (a region surrounded by an electrolyte that extends infinitely far away, as the outer surface of a ship) and a closed region (a region surrounding an electrolyte, as the inner surface of a pump) with respect to each of two-dimensional, three-dimensional, and axially symmetric objects, and solved practical corrosion and corrosion prevention problems.

In actual system, some of six regions that can be modeled as two-dimensional objects (open and closed regions), three-dimensional objects (open and closed regions), and axially symmetric objects (open and closed regions) are present continuously. FIG. 3 of the accompanying drawings show a specific example. FIG. 3 shows a seawater pump of stainless steel having Zn sacrificial anodes disposed in three locations on the inner surface thereof and four Zn sacrificial anodes in the form of prisms spaced at equal intervals on the outer surface thereof. The

inner and outer surfaces of the pump are connected to each other via seawater, so that the inner surface should electrochemically affect the outer surface and the outer surface should electrochemically affect the inner surface.

However, the seawater surrounding the outer surface of the pump occupies a wide region, and boundaries for dividing the outer surface are too large to handle it as a closed region. It is practically impossible to model and simultaneously analyze the outer surface as a three-dimensional closed region as with the inner surface. Therefore, the inner surface of the pump is analyzed as a three-dimensional closed region, and the outer surface of the pump as an open region. The inner surface of a guide casing is divided into seven flow paths by seven helical guide vanes. Since these flow paths are symmetrical, one of them is taken and divided into three-dimensional elements. The prismatic anodes on the outer surface of the pump are handled as axially symmetric on the assumption that strip-shaped anodes of the same area are mounted on the outer surface of the pump, and handled as open-region axially symmetric models.

Actually, since the inner and outer surfaces of the pump electrochemically affect each other, they need to be analyzed taking that consideration into account. However, because analyzing programs for handling the respective regions are different from each other (the inner surface of the pump: a three-dimensional closed-region program, the outer surface of the pump: an axially symmetric open-region

program), it has heretofore been impossible to perform an analysis taking the effect of the regions on each other into account. While the inventor has developed the region dividing method, as described above, the developed method can only analyze regions modeled in the same manner.

Disclosure of Invention

The present invention has been made in view of the above drawbacks. It is an object of the present invention to provide a method of analyzing corrosion and corrosion prevention in a system where two or more same or different regions of six regions that are modeled as two-dimensional objects (open and closed regions), three-dimensional objects (open and closed regions), and axially symmetric objects (open and closed regions) are present continuously, the method being capable of analyzing the two or more different regions that are present continuously.

According to an invention defined in claim 1, there is provided a method of analyzing corrosion and corrosion prevention in a system where two or more same or different regions of six regions that are modeled as two-dimensional objects (open and closed regions), three-dimensional objects (open and closed regions), and axially symmetric objects (open and closed regions) are present continuously, characterized by the steps of dividing the system into regions and dividing each of the regions into elements depending on respective models (two-dimensional, three-dimensional, and axially symmetric) thereof, and using one

of the regions as an attentional region and another as a non-attentional region, and giving varying values of a current density or a potential to the elements where current densities and potentials on the elements which are positionally the same as each other on a division plane disposed between and shared by two regions are equivalent to each other, the relationship between the current densities and potentials on the elements being unknown, solving a discrete boundary integral equation corresponding to the non-attentional region for the given values of the current density or the potential thereby to express the unknown relationship between the current densities and potentials on the division plane with the known relationship between current densities and potentials on elements in the non-attentional region other than the division plane, performing a boundary element analysis on the attentional region using the determined relationship between the current densities and potentials on the division plane as a boundary condition on the division plane thereby to determine potential and current density distributions in the attentional region in its entirety, and performing a boundary element analysis on the non-attentional region again using the determined potentials or current densities on the division plane thereby to analyze the regions in a related manner.

According to an invention defined in claim 2, there is provided a method of analyzing corrosion and corrosion prevention in a system where two or more non-attentional regions are present continuously with respect to the one

attentional region, characterized by the steps of determining the relationship between current densities and potentials with respect to both division planes in the method according to claim 1, analyzing the attentional region using the determined relationship as a boundary condition to determine potential and current density distributions in the attentional region in its entirety, and performing a boundary element analysis on the non-attentional region again using the determined potentials or current densities on the division planes thereby to analyze the regions in a related manner.

According to the present invention, the discrete boundary integral equation corresponding to the non-attentional region is solved to express the unknown relationship between the current densities and potentials on the division plane with the known relationship between current densities and potentials on elements in the non-attentional region other than the division plane. In this manner, the relationship between the current densities and potentials on the division plane in the non-attentional region can be obtained, and the attentional region can be analyzed from the obtained relationship on the division plane taking the non-attentional region into account. Therefore, the different regions can be continuously analyzed in a relatively short time.

The method according to the present invention is also applicable to a system where two or more non-attentional regions are present continuously with respect to

one attentional region.

Brief Description of Drawings

FIG. 1 is a diagram illustrative of boundary conditions for determining a potential or current density distribution;

FIG. 2 is a diagram illustrative of the division of regions;

FIG. 3 is a view showing a structure of a seawater pump as an example of an object to be analyzed;

FIG. 4 is a diagram showing two different regions that are present continuously;

FIGS. 5A and 5B are views showing the division of regions of the seawater pump; and

FIGS. 6A through 6C are views showing the results of an analysis of the seawater pump, FIG. 6A showing the shape of the pump (segment positions), FIG. 6B showing a potential distribution on the inner surface of the pump, and FIG. 6C showing a potential distribution on the outer surface of the pump.

Best Mode for Carrying Out the Invention

FIG. 4 shows a region Ω that is divided into two different regions Ω_1, Ω_2 that are present continuously. Boundary elements Γ_1, Γ_2 of those regions Ω_1, Ω_2 are partly known. Γ_B represents a boundary element on the dividing plane, which has a potential and a current density that are common as viewed from the region Ω_1 or the region Ω_2.

When an ordinary boundary element method is applied to an attentional region, the following discrete equation is obtained:

$$[H_2]\begin{Bmatrix}\phi^2 \\ \phi_B^2\end{Bmatrix} = [G_2]\begin{Bmatrix}q^2 \\ q_B^2\end{Bmatrix} \tag{18}$$

where ϕ^2 and q^2 represent a potential and a current density on the boundary Γ_2, $\phi_B{}^2$ and $q_B{}^2$ represent a potential and a current density on the boundary Γ_B as seen from the region Ω_2, and $[H_2]$ and $[G_2]$ represent coefficient matrixes obtained by applying the ordinary boundary element method. If the entire boundary surrounding the region Ω_2 is made up of n elements, then it is assumed that the n elements include m elements on the boundary Γ_2 and one element on the boundary Γ_B.

When the unknown boundary nodal point quantity is transferred to the left side and the known boundary nodal point quantity is transferred to the right side in the equation (18) to change the equation (18) to a form $Ax = b$ and the boundary condition on the boundary Γ_2 is substituted, the following equation is obtained:

x represents a vector composed of an unknown potential or current density, b represents a constant-term vector after the known boundary condition is substituted, and A represents a coefficient matrix determined by H, G matrixes and the gradient of the polarization curve.

$$\begin{bmatrix} a_{11} & \cdots & \cdots & a_{1n+l} \\ \vdots & & & \vdots \\ a_{n1} & \cdots & \cdots & a_{nn+1} \end{bmatrix} \begin{Bmatrix} \phi^2_? \\ q^2_? \\ \phi^2_B \\ q^2_B \end{Bmatrix} = \begin{Bmatrix} b_1 \\ \vdots \\ b_n \end{Bmatrix}$$

(19)

where $\phi^2{}_?$, $q^2{}_?$ represent an unknown potential and current density on the boundary Γ_2, x represents an m + 21 row vector, vector b represents an n row vector, and matrix A represents a matrix having a size of nx (m + 21).

The matrix A is divided as follows:

$$A = \begin{bmatrix} a_{11} & \cdots & \cdots & a_{1n+l} \\ \vdots & & & \vdots \\ a_{n1} & \cdots & \cdots & a_{nn+1} \end{bmatrix}$$

$$\left[\begin{array}{c|c} A_{22} & A_{2I} \\ \hline A_{I2} & A_{II} \end{array}\right] \begin{Bmatrix} \phi^2_? \\ q^2_? \\ \phi^2_B \\ q^2_B \end{Bmatrix} = \left\{\begin{array}{c} B_2 \\ \hline B_I \end{array}\right\}$$

(20)

When $\phi^2{}_?$ and $q^2{}_?$ are erased from the equation (20), the relationship between $\phi^2{}_B$ and $q^2{}_B$ according to the following equation is obtained:

$$\{[A_{II}] - [A_{I2}][A^I_{22}][A_{2I}]\} \begin{Bmatrix} \phi^2_B \\ q^2_B \end{Bmatrix} = \{B_I\} - [A_{I2}][A^{-1}_{22}]\{B_2\}$$

(21)

The equation (21) is an equation representing the relationship between the boundary nodal point quantities $\phi^2{}_B$ and $q^2{}_B$ on the boundary Γ_B. This equation represents the relationship between $\phi^2{}_B$ and $q^2{}_B$ taking into account the effect of the non-attentional region Ω_2, and is considered as a boundary condition equivalent to the effect of the non-

attentional region. If this boundary condition is given as a boundary condition for Γ_B, then it is possible to analyze an attentional region taking into account the effect of the non-attentional region. Specifically, the attentional region is analyzed using, as the boundary condition, a potential or current density on Γ_B, which has been obtained by analyzing the non-attentional region. When the non-attentional region is further analyzed based on the potential or current density on the obtained division plane, the analysis of all the regions is completed.

The object to be analyzed comprises a vertical-shaft pump having a diameter of 200 mm and a length of 6000 mm, as shown in FIG. 3. As shown in FIGS. 5A and 5B, the pump is divided into inner pump portions 15, 16 and an outer pump portion 17. The inner surface of the pump is divided into a guide casing 15 of complex three-dimensional shape comprising a combination of complex members and having a helical flow path, and a column pipe 16 that can be modeled axially symmetrically. The three regions thus divided include a pump outer surface, a guide casing inner surface, and a column pipe inner surface which are handled as an axially symmetric open region, a three-dimensional closed region, and an axially symmetric closed region, respectively. The guide casing inner surface is divided into seven flow paths by seven helical guide vanes. Since these flow paths are symmetrical, one of them is taken and divided into three-dimensional elements.

In order to determine the relationship between a

potential Vs and a current density q on boundary surfaces Γ_a, Γ_b between the pump outer surface and the column pipe inner surface, and the guide casing, the pump outer surface and the column pipe inner surface are handled as non-attentional regions, and subjected to a boundary element analysis. The former is subjected to an axially symmetric open-region analysis, and the latter to an axially symmetric closed-region analysis.

Using the obtained relationship between the potential and the current density as a boundary condition, the guide casing (attentional region) is subjected to a three-dimensional closed-region analysis. Using current densities on the boundary surfaces Γ_a, Γ_b obtained from this analysis as boundary conditions, the pump outer surface and the column pipe inner surface are analyzed again, whereupon all analyses are completed. FIGS. 6A through 6C show the results of the analyses as representing potential distributions on the pump inner and outer surfaces.

FIG. 6A shows the shape of the pump (segment positions) to be analyzed. In FIG. 6A, the horizontal axis represents the radial position, and the vertical axis the axial position. FIG. 6B shows a potential distribution on the pump inner surface, and FIG. 6C shows a potential distribution on the pump outer surface. At the positions of sacrificial anodes 11a, 11b, 11c shown in FIG. 3, the potential on the pump inner surface is highly negative, and the potential is of about - 0.4 [V] in portions other than the sacrificial anodes. It can thus be seen that while the

potential would usually be of about 0 [V] if no sacrificial anodes were used on a stainless pump in seawater, the sacrificial anodes are highly effective to prevent corrosion. This holds true for the pump outer surface. A region between Γ_a, Γ_b is an attentional region (guide casing), and other regions are non-attentional regions. On these division planes Γ_a, Γ_b, the potential distribution is continuous. It can be seen from the continuous potential distribution that continuous analytic results between different regions can be obtained by the related analysis between the different regions.

The above embodiment represents an example of the present invention, and can be modified in various ways without departing from the scope of the invention.

Heretofore, complex fields where two or more of different six regions that are modeled as two-dimensional objects (open and closed regions), three-dimensional objects (open and closed regions), and axially symmetric objects (open and closed regions) are present continuously have to be analyzed separately. In the method according to the present invention, it is possible to analyze those fields in a related fashion.

For example, heretofore, the inner and outer surfaces of a vertical-shaft pump have been analyzed separately though they electrochemically affect each other, and cannot accurately be analyzed for corrosion and corrosion prevention. In the method according to the present invention, however, it is possible to analyze the

pump inner and outer surfaces in a related manner in a relatively short time. While the entire pump inner surface has heretofore been analyzed using a three-dimensional closed-region model, the method according to the present invention makes it possible to analyze the column pipe inner surface of simple shape using an axially symmetric model, allowing the surface to be divided into elements with ease.

If a three-dimensional region and an axially symmetric region are present continuously, then it has not been possible to accurately determine a region that can be modeled axially symmetrically. According to the present invention, however, the regions can clearly be distinguished from each other as described above, and a potential distribution and a current density distribution can easily be analyzed at the boundary region, so that effective corrosion prevention measures can be taken.

Industrial Applicability

The present invention relates to a method of analyzing corrosion and corrosion prevention with a computer, and can be used to predict corrosion and corrosion prevention for various devices such as pumps installed in seawater, water, and soil. The method can be used for a computer simulation of a system, such as a plating facility, a battery cell, or an electrolysis tank, where an anode and a cathode are macroscopically present with an electrolyte interposed therebetween to form a potential field, other than the problems of metal corrosion and corrosion

prevention.

CLAIMS

1. A method of analyzing corrosion and corrosion prevention in a system where two or more same or different regions of six regions that are modeled as two-dimensional objects (open and closed regions), three-dimensional objects (open and closed regions), and axially symmetric objects (open and closed regions) are present continuously, characterized by:

dividing the system into regions and dividing each of the regions into elements depending on respective models (two-dimensional, three-dimensional, and axially symmetric) thereof, and using one of the regions as an attentional region and another as a non-attentional region;

giving varying values of a current density or a potential to the elements where current densities and potentials on the elements which are positionally the same as each other on a division plane disposed between and shared by two regions are equivalent to each other, the relationship between the current densities and potentials on the elements being unknown;

solving a discrete boundary integral equation corresponding to the non-attentional region for the given values of the current density or the potential thereby to express the unknown relationship between the current densities and potentials on the division plane with the known relationship between current densities and potentials on elements in the non-attentional region other than the

division plane;

performing a boundary element analysis on the attentional region using the determined relationship between the current densities and potentials on the division plane as a boundary condition on the division plane thereby to determine potential and current density distributions in the attentional region in its entirety; and

performing a boundary element analysis on the non-attentional region again using the determined potentials or current densities on the division plane thereby to analyze the regions in a related manner.

2. A method of analyzing corrosion and corrosion prevention in a system, where two or more non-attentional regions are present continuously with respect to one said attentional region, characterized by:

determining the relationship between current densities and potentials with respect to both division planes in the method according to claim 1,

analyzing the attentional region using the determined relationship as a boundary condition to determine potential and current density distributions in the attentional region in its entirety, and

performing a boundary element analysis on the non-attentional region again using the determined potentials or current densities on the division planes thereby to analyze the regions in a related manner.

3. A method of analyzing corrosion and corrosion prevention of a pump according to claim 2, characterized in that said attentional region comprises a closed region of three-dimensional shape in a guide casing of a pump, and the non-attentional regions comprise an axially symmetric closed region of a column pipe on an inner surface of the pump which is contiguous to said guide casing, and an axially symmetric open region of an outer surface of the pump.

4. A method of analyzing corrosion and corrosion prevention of a pump according to claim 3, characterized in that anodes are disposed in some or all of the regions of the pumps and a corrosion prevention effect of the anodes is evaluated.

ABSTRACT

The present invention provides a method of analyzing corrosion and corrosion prevention in a system where two or more same or different regions of regions that are modeled as two-dimensional, three-dimensional, and axially symmetric regions are present continuously.

The entire system is divided into regions, and each of the regions is divided into elements depending on respective models thereof, with one of the regions used as an attentional region and another as a non-attentional region. A division plane is shared by the two regions, and current densities and potentials on the elements which are positionally the same as each other on the division plane are equivalent to each other. A discrete boundary integral equation corresponding to the non-attentional region is modified to express the unknown relationship between current densities and potentials on the division plane with the known relationship between current densities and potentials on elements in the non-attentional region other than the division plane. A boundary element analysis is performed on the attentional region using the determined relationship between the current densities and potentials on the division plane as a boundary condition thereby to determine potential and current density distributions in the attentional region in its entirety. Then, a boundary element analysis is performed on the non-attentional region again using the determined potentials or current densities on the division

plane thereby to analyze the regions in a related manner.

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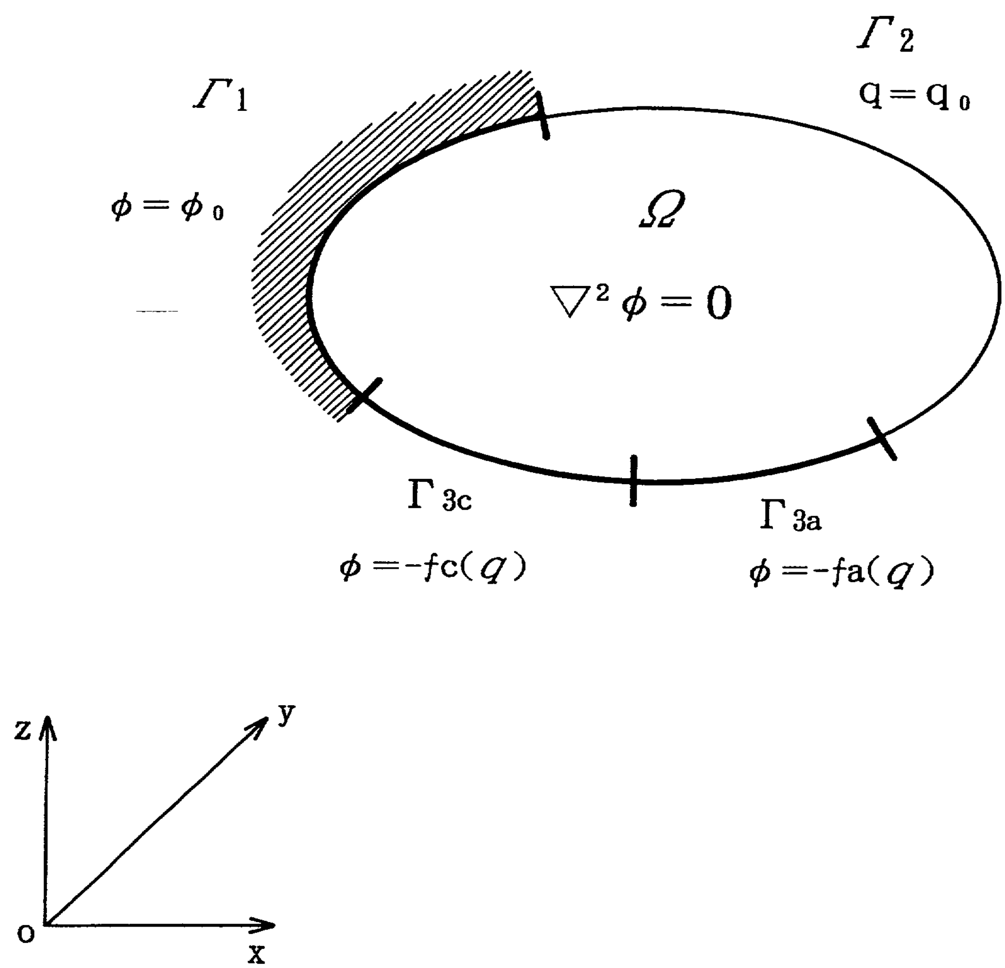

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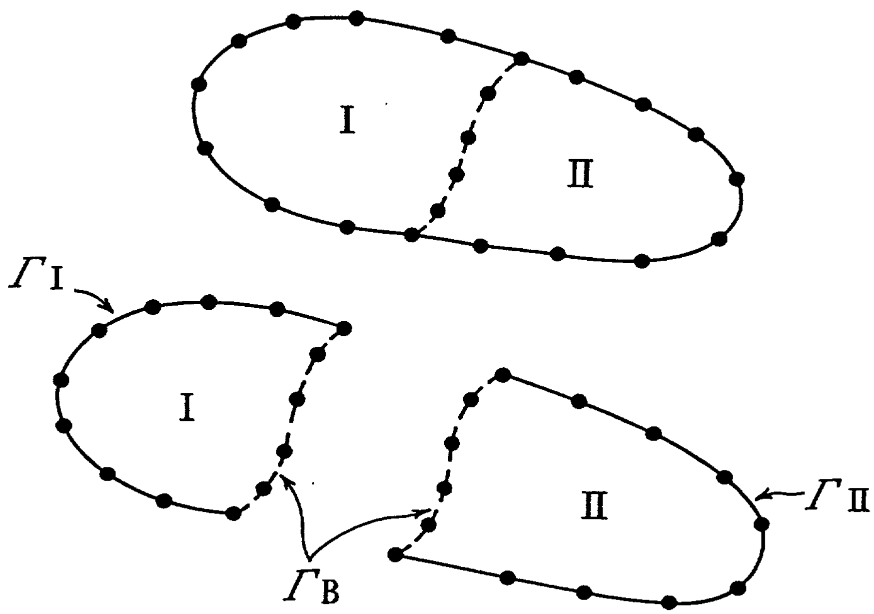

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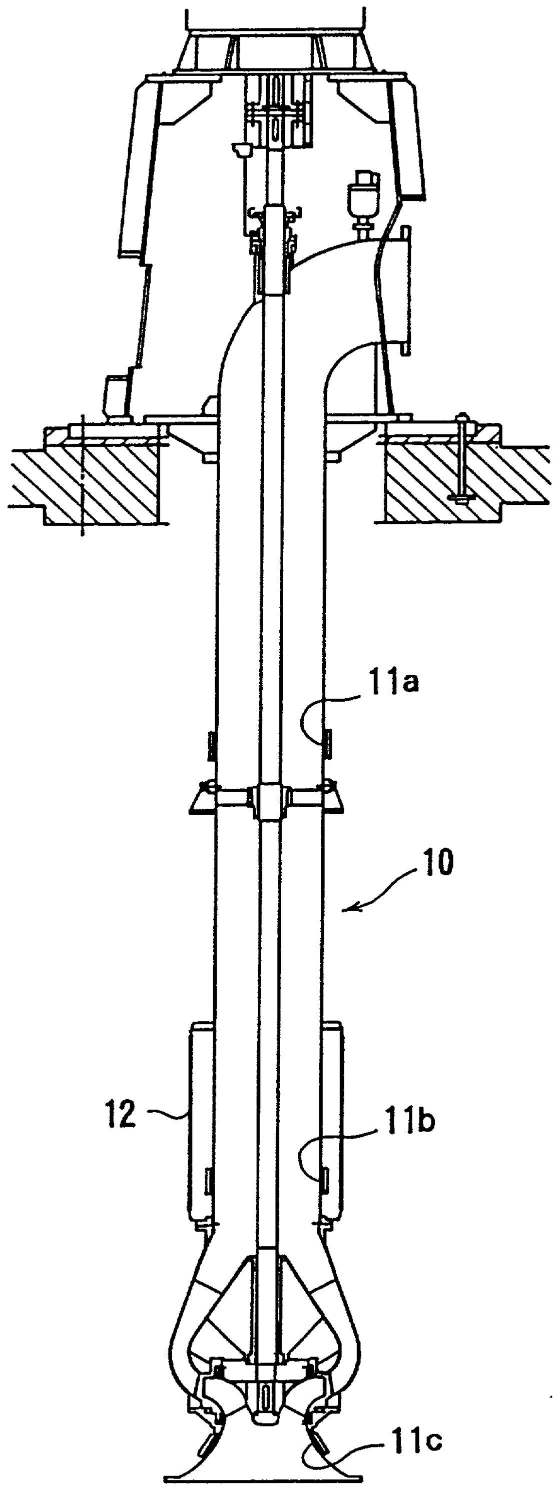

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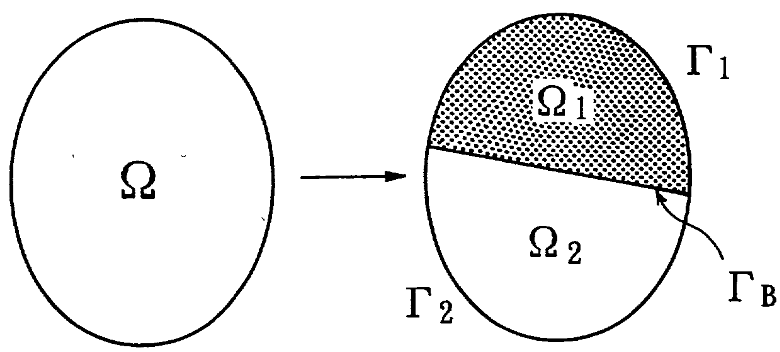

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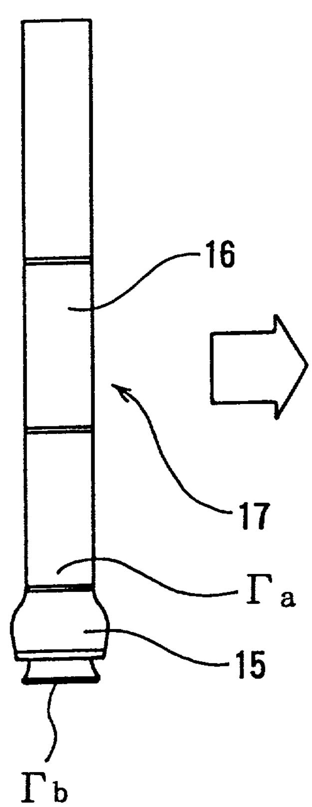

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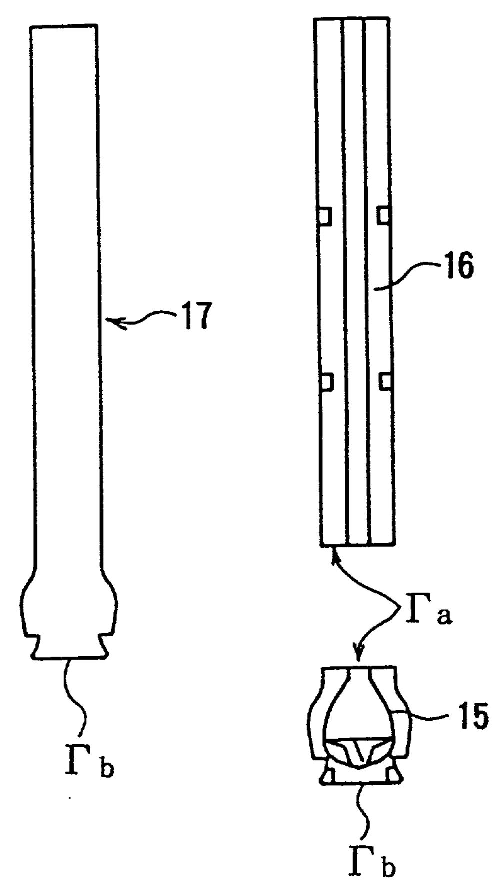

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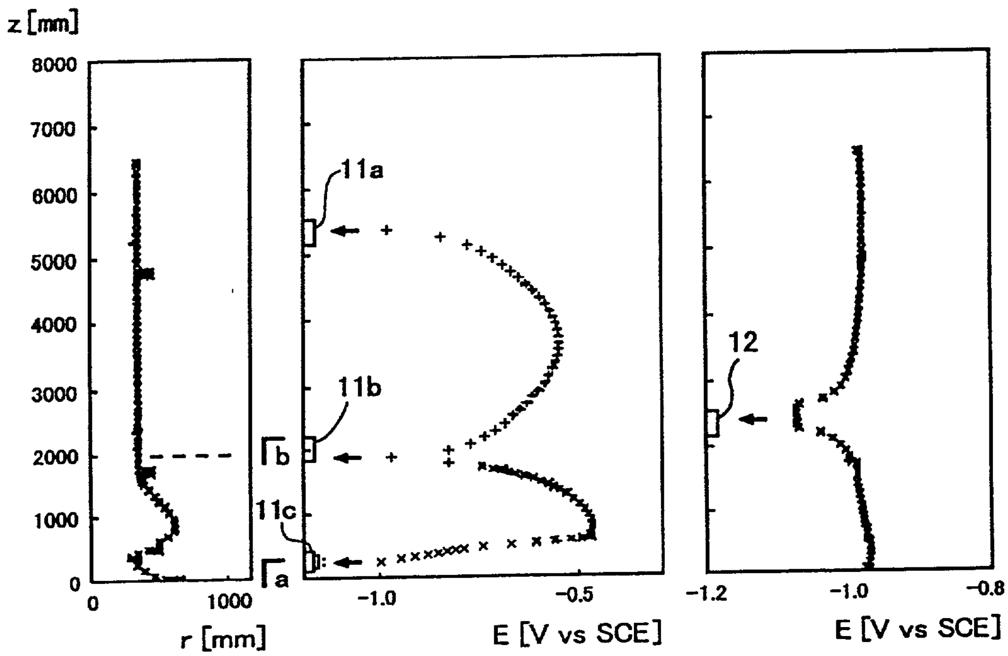
F I G. 6A F I G. 6B F I G. 6C



Declaration and Power of Attorney For Patent Application

特許出願宣言書及び委任状

Japanese Language Declaration

日本語宣言書

下記の氏名の発明者として、私は以下の通り宣言します。

As a below named inventor, I hereby declare that:

私の住所、私書箱、国籍は下記の私の氏名の後に記載された通りです。

My residence, post office address and citizenship are as stated next to my name.

下記の名称の発明に関して請求範囲に記載され、特許出願している発明内容について、私が最初かつ唯一の発明者（下記の氏名が一つの場合）もしくは最初かつ共同発明者（下記の名称が複数の場合）であると信じています。

____

____

____

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled.

METHOD OF ANALYZING CORROSION

AND CORROSION PREVENTION

____

上記発明の明細書は、

- ☐ 本書に添付されています。
- ☐ ___月___日に提出され、米国出願番号または特許協定条約国際出願番号を________とし、(該当する場合) ________に訂正されました。

the specification of which

- ☐ is attached hereto.
- ☒ was filed on September 20, 1999 as United States Application Number or PCT International Application Number PCT/JP99/05110 and was amended on April 4, 2000 (if applicable).

私は、特許請求範囲を含む上記訂正後の明細書を検討し、内容を理解していることをここに表明します。

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

私は、連邦規則法典第37編第1条56項に定義されるとおり、特許資格の有無について重要な情報を開示する義務があることを認めます。

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

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私は、米国法典第35編119条（a）-（d）項又は365条（b）項に基づき下記の、米国以外の国の少なくとも一ヵ国を指定している特許協力条約365（a）項に基づく国際出願、又は外国での特許出願もしくは発明者証の出願についての外国優先権をここに主張するとともに、優先権を主張している、本出願の前に出願された特許または発明者証の外国出願を以下に、枠内をマークすることで、示しています。

I hereby claim foreign priority under Title 35, United States Code, Section 119 (a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)
外国での先行出願

(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	Priority Claimed 優先権主張 Yes はい	No いいえ
10-279191	Japan	30/September/1998	☒	☐
			☐	☐

☐ 私は、第35編米国法典119条（e）項に基づいて下記の米国特許出願規定に記載された権利をここに主張いたします。

I hereby claim the benefit under Title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below.

(Application No.) (出願番号)	(Filing Date) (出願日)	(Application No.) (出願番号)	(Filing Date) (出願日)

☐ 私は、下記の米国法典第35編120条に基づいて下記の米国特許出願に記載された権利、又は米国を指定している特許協力条約365条（c）に基づく権利をここに主張します。また、本出願の各請求範囲の内容が米国法典第35編112条第1項又は特許協力条約で規定された方法で先行する米国特許出願に開示されていない限り、その先行米国出願書提出日以降で本出願書の日本国内または特許協力条約国際提出日までの期間中に入手された、連邦規則法典第37編1条56項で定義された特許資格の有無に関する重要な情報について開示義務があることを認識しています。

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of application.

(Application No.) (出願番号)	(Filing Date) (出願日)	(Status: Patented, Pending, Abandoned) (現況：特許許可済、係属中、放棄済)

私は、私自信の知識に基づいて本宣言書中で私が行なう表明が真実であり、かつ私の入手した情報と私の信じるところに基づく表明が全て真実であると信じていること、さらに故意になされた虚偽の表明及びそれと同等の行為は米国法典第18編第1001条に基づき、罰金または拘禁、もしくはその両方により処罰されること、そしてそのような故意による虚偽の声明を行なえば、出願した、又は既に許可された特許の有効性が失われることを認識し、よってここに上記のごとく宣誓を致します。

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Japanese Language Declaration
(日本語宣言書)

委任状：私は下記の発明者として、本出願に関する一切の手続きを米特許商標局に対して遂行する弁理士または代理人として、下記の者を指名いたします。
(弁護士、または代理人の指名及び登録番号を明記のこと)

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: *(list name and registration number)*

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（日本語宣言書）

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第六の共同発明者の署名　日付	Sixth joint Inventor's signature　Date
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（第六またはそれ以降の共同発明者に対しても同様な情報および署名を提供すること。）

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